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ARTICLE

A Time-Cost Analysis of Operating Room Utilization and Efficiency in Cardiac Surgery

Suvitesh Luthra[1,2,*], Gabriel Hunduma[1], Ahmed Eissa[1], Laura Viola[1], Szabolcs Miskolczi[1], Theodore Velissaris[1]

[1]Division of Cardiothoracic Surgery and Anaesthesia, University Hospital Southampton, Southampton, UK
[2]School of Human Development and Health, Faculty of Medicine, University of Southampton, Southampton, UK
*Correspondence: s.luthra@soton.ac.uk (Suvitesh Luthra)

Abstract

Aims/Background The aim of this analysis was to determine Operating Room (OR) utilization efficiencies and costs in cardiac surgery.

Methods A retrospective cohort of 1987 cardiac surgeries were analyzed over a 2-year period for surgeon idling time, knife-to-skin time, procedure time, total operation time and transfer times in a two-case/block model. Predefined indices of operational efficiency (Index of Operational Efficiency [InOE], Surgical Index of Operational Efficiency [sInOE]) were calculated for various procedures and teams. The goodness of fit of regression curves were performed for InOE for various times on the operational pathway.

Results The mean 'procedure time' was 246 ± 73 minutes (78% of total OR time). OR utilization efficiencies were highest for aortic valve replacement (AVR) and coronary artery bypass surgery (CABG) and least for complex aortic procedures. Significant differences existed for procedure-specific and team-specific OR times and operational efficiency. Procedure times correlated strongest with InOE (r = –0.940, $p < 0.001$). They had a closer linear fit to regression curve analysis thus indicating greater efficiency.

Conclusion There were significant variations between OR times and efficiencies for procedures and teams. Significant cost savings are possible by increasing efficiency along the operational pathways in cardiac surgery theatres.

Key words: cardiac surgery; operating room; operation research; operating time; utilization; efficiency; cost

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Introduction

The National Health Service (NHS) has faced unprecedented challenges in recent times. Department of Health and Social Care, United Kingdom (UK) spends in excess of £165 billion (1GBP = 1.2USD) for the NHS budget which accounts for almost 12% of UK's Gross Domestic Product. The deficits in the NHS funding streams exceed £20 billion (Barron, 2024). Emerging from the coronavirus disease-19 (COVID-19) pandemic, there was a massive backlog of cases with long waiting lists for cardiac surgery. Brexit added to these woes in a number of ways including paucity of healthcare workers, decreased recruitment, lack of funding and increasing financial strains (Public Expenditure Statistical Analyses, 2022). This was

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further worsened by the healthcare workers' strikes related to demands of pay increments in the UK. Capacities and efficiencies in the system have suffered across the board but super specialist areas like cardiac surgery bore the brunt of the impact due to reduced bed capacity, no ring fencing, competition for resources from generalists and emergency services involved with COVID-19, challenges with recruitment of trained workforce and reduced funding.

Operating Room (OR) remains one of the key areas in cardiac surgery care pathway and utilization efficiencies have a deep impact on throughput and waiting lists. The Get It Right First Time (2024) national programme set an OR utilisation goal of 85% by 2024/25, suggesting efficient use can prevent delays in the pathway and directly reduce bed pressures and waiting lists. It identified potential causes of lower OR productivity, which included inter-case downtime, late start times, insufficient equipment supply, and delayed sending for first cases. It advised areas of improvement to achieve the targeted 85% OR touch time utilisation.

Costs for cardiac procedures are more intensive compared to other surgical procedures. There is very limited literature on OR utilization efficiency in cardiac surgery procedures that require more complex organizational pathways and greater planning and resourcing for manpower (larger teams of anaesthetists, perfusionists, surgeons, surgical care practitioners, physiologists, OR technicians, scrub and floor nursing staff), time and costs. Although the operational pathways are well established in cardiac surgery despite their acknowledged complexities, there are no well-defined indices for operational utilization efficiencies to measure variations of practice, aid comparison or analysis between procedures and teams. We know that inefficiencies lead to cost escalations in systems. However, the direct linkages and exact measures between efficiencies of utilization in the cardiac operational pathways and its implications on objective linked measurements of costs remain largely unknown and unexplored in a systematic manner. We hypothesised that there are significant variations and resultant inefficiencies in OR times for procedures and teams in the cardiac surgical operational pathway and this leads to significant costs which can be improved.

The aims of this analysis were to:

(1) Determine OR utilization and efficiencies in cardiac surgery.

(2) Time-cost analysis of utilization and efficiencies.

We further analysed the cardiac surgery care pathway in the OR to improve performance, utilization and cost savings. This unique study also serves as a template to build an analytic framework for standard use in the NHS to establish a direct linkage between operational efficiencies and costs with the use of novel efficiency indices for operational pathways.

Methods

Study Design

This single-centre, quality improvement study was conducted at a large quaternary care teaching hospital in the UK. Data were retrospectively collected from the Patient Administration System—Electronic Clinical and Management Information System (eCaMIS, EMIS, Leeds UK) from Jan 2020 to Apr 2022. All patient-identifiable data were excluded. The project was registered as a service improvement project (Safeguard 7872, 29/03/2024) in compliance with the trust data management policies. Consent was not required due to the nature of the study as a service improvement and a quality initiative.

Inclusion and Exclusion Criteria

All patients brought to the OR for a cardiac surgical procedure (elective, urgent and emergency) and recorded in the database for the period were included. We excluded salvage procedures directly from the Cathlab and those procedures where the patient died in the anaesthetic room (during induction) or in the OR (after induction) prior to the commencement of the operation. All cases with missing data were excluded.

Data Collection and Definitions of Times

Variables collected included the type of surgery, various recorded times at which the patient was sent for, arrival in the anaesthetic room, arrival in OR, knife-to-skin, skin closure time and transfer out time. These recorded times from the database were used to calculate the defined study time points (preparation time, knife-to-skin time, procedure time, transfer time and total OR times). The times were defined as follows;

(1) Preparation time—from arrival in the anaesthetic room to transfer to OR after induction.

(2) Knife-to-skin time—time of making the skin incision after arrival in the OR.

(3) Procedure time—from knife-to-skin time to closure of all the incisions and dressings.

(4) Transfer time—from closure of all incisions to transfer out (after all checks and final counts are completed).

(5) Total OR time—from transfer to the anaesthetic room to transfer out from the OR.

(6) Surgeon idling times—time spent 'un-scrubbed', whilst awaiting patient transfer, anaesthetic time, until initiation of knife-to-skin time.

The standard operating day for an OR was identified as an 8-hour block with 2 cardiac cases with an estimated 4 hours (240 min) of OR time per case. This was based on the working time shifts for the OR staff (this excluded the emergency on-call OR running times for simplicity of calculations). The calculations were not risk-stratified per case. We analysed each step of the cardiac surgery pathway for each case performed. The steps include time to transfer in/out, preparation time, surgeon idling time, anaesthetic start time, knife-to-skin time, procedure time, total OR time, and operation start and finish times (Fig. 1A). Times were recorded in minutes for all categories.

Definitions for Operational Indices

Indices of Operational Efficiencies were defined by Luthra et al (2015) as follows based on the 2 cases/8 hr block model.

Index of Operational Efficiency (InOE)

InOE (%) = 100 – {(total OR time – 240) × 100/240}

Surgical Index of Operational Efficiency (sInOE)

sInOE (%) = 100 – {(total OR time – procedure time) × 100/240}

Data Analysis

Continuous data was expressed as means (with standard deviations) or medians (with interquartile ranges). The chi-square test was used for categorical variables and Kruskal-Wallis test for the comparison of continuous variables. A p-value $<$ 0.05 was considered statistically significant. Spearman's correlation coefficient was calculated (SPSS v29.0, IBM, Armonk, NY, USA) for operational efficiencies and various times of the operational pathway. Regression analysis curves were plotted, comparing the relationship of the operational efficiencies with selected steps of the pathway. Execution times corresponding to each step of the pathway performed by various cardiac surgical teams were analysed. A time-cost analysis was performed using standard operating costs and inflation-adjusted OR running costs in the NHS (Fletcher et al, 2017; National tariff payment system documents, 2023). Time overrun costs were calculated based on this analysis. All times (minutes) and costs (GB Pounds - £) were expressed as mean ± standard deviation.

Results

A retrospective sample of 1987 cases over a 2-year period was analysed. Cases included 622 (31.3%) coronary artery bypass surgery (CABG), 588 (29.6%) aortic valve replacements (AVR), 190 (9.6%) mitral valve replacements (MVR), 189 (9.5%) aortic procedures, and 398 (20%) miscellaneous cardiac procedures.

Times Along the Operational Pathway

The total OR time/case was 315.3 ± 79.1 minutes and the mean procedure time was 246 ± 73 minutes (**Supplementary Table 1**). Knife-to-skin constituted 21% (68.4 ± 22 minutes), transfer time constituted 17% of the average total operating time (55 ± 22 minutes).

The procedure time for major aortic cases encompassed a greater portion of the allotted 4-hour block (Table 1, Fig. 1B).

Procedure and Team Specific InOE/sInOE

CABG demonstrated greater operational efficiency (InOE 75%) compared to the least efficient complex aortic surgeries (InOE 50%). Spearman's correlation coefficients confirmed a significant negative correlation to the OR efficiencies (Table 2). Procedure times demonstrated the strongest correlation to InOE (r = –0.940, $p < 0.001$), compared to preparation time (r = –0.378, $p < 0.001$) and transfer time (r = –0.377, $p < 0.001$) (Fig. 2). There were significant team specific differences in total operation times and delivered InOE and sInOE. Team A demonstrated greater

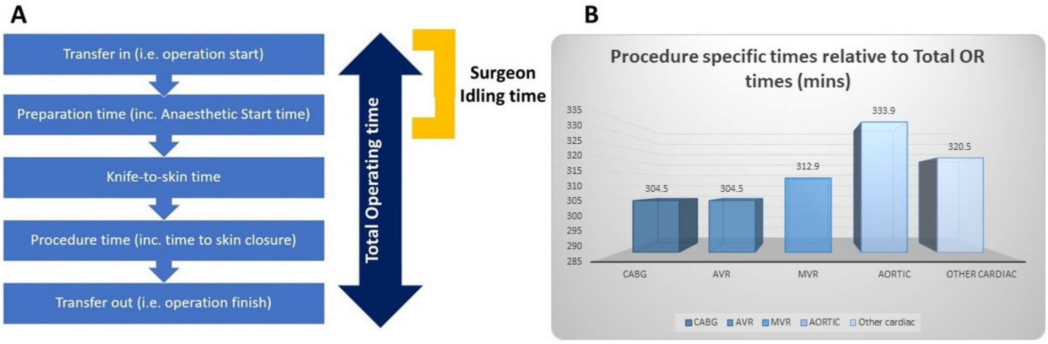

Fig. 1. Operational pathway and procedure specific times. (A) Cardiac surgery case-specific operational pathway used in the model. (B) Procedure-specific times. OR, Operating Room.

operational efficiencies (InOE: 76.0 ± 26.0, sInOE: 72.0 ± 8.0) compared to other teams (Table 1) as well as the fastest total operative time (Table 1). A greater disparity in team dynamics, with better functionality in Team A, was observed in contrast to Team F (p = 0.043).

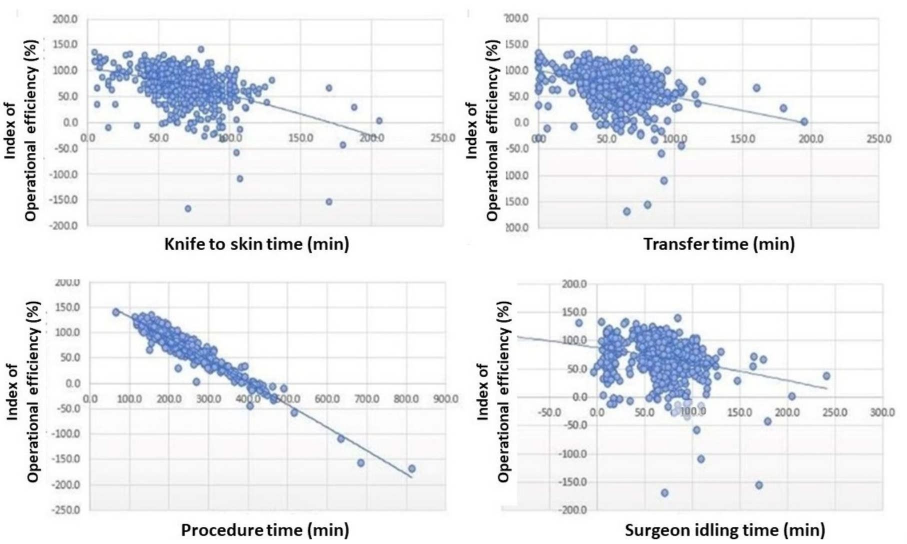

Fig. 2. Regression curves for various times along the pathway against InOE.

Time-Cost Analysis of the Operational Pathway

The individual costs of the various times along the operational pathway were calculated for the period of the study (Table 3). The total 2-year cost of surgeon-idling time amounted to £2,973,360.00. Costings for transfer time were £2,673,180.00 of the amount, compared to anaesthetic time which accounted for £300,180.00. Procedure time costs were £11,508,540.00 and total operation time costs of £14,468,100.00. There was a significant variation between teams for InOE which translated to differing total operating times and costings (Fig. 3).

A time cost analysis with a 10- and 20-minute reduction in the transfer times demonstrated savings of £286,920.00 and £573,960.00 respectively (Table 3). Fur-

Table 1. Team- and procedure-based analysis of specific times for cases and operational efficiencies (values are median values with interquartile ranges in parenthesis).

Teams	CABG (min)	MVR (min)	AVR (min)	Major aortic (min)	Other cardiac (min)	Procedure time (min)	Total OR time (min)	InOE (%)	sInOE (%)
A	227.5 (192.3–269.2)	215.0 (186.0–253.0)	215.0 (176.5–263.5)	215.0 (195.0–308.0)	213.5 (190.5–268.2)	217.0 (185.0–264.2)	280.5 (238.7–333.0)	83.1 (61.3–100.5)	72.9 (67.7–80.8)
B	230.0 (198.0–261.5)	226.5 (195.0–270.3)	235.0 (198.5–273.7)	247.0 (213.5–275.5)	229.0 (192.0–258.5)	229.0 (196.0–263.0)	286.0 (247.0–335.0)	80.8 (60.4–97.1)	72.9 (66.7–84.2)
C	235.0 (210.0–270.0)	226.0 (200.0–259.0)	238.0 (195.2–291.5)	271.0 (218.2–330.0)	255.0 (210.0–306.5)	234.5 (198.0–278.5)	301.5 (255.8–345.0)	74.4 (56.3–93.4)	72.5 (65.8–80.9)
D	240.5 (209.2–280.0)	275.5 (229.7–308.8)	237.0 (200.0–289.0)	245.5 (195.0–282.0)	245.5 (195.5–287.3)	238.0 (206.0–281.0)	310.0 (263.0–350.0)	70.8 (54.2–90.4)	72.1 (65.4–77.5)
E	254.0 (222.0–292.8)	227.0 (199.8–288.7)	221.0 (189.5–250.5)	257.0 (207.0–268.5)	240.0 (220.0–268.5)	238.0 (195.7–260.7)	302.5 (258.8–337.7)	74.0 (59.3–92.2)	69.2 (66.5–75.8)
F	227.0 (202.5–269.5)	279.0 (234.2–293.2)	227.5 (191.0–262.7)	224.5 (201.3–277.7)	218.0 (189.0–265.0)	223.0 (195.0–265.0)	290.0 (247.0–325.5)	79.2 (64.4–97.1)	74.2 (68.5–83.7)
G	231.0 (204.0–260.0)	NA	228.0 (200.5–273.5)	233.0 (214.0–335.0)	252.0 (229.5–284.5)	228.5 (195.0–257.0)	292.0 (257.8–325.0)	78.3 (64.6–92.6)	72.7 (66.7–79.2)
H	227.0 (200.0–275.0)	241.0 (206.5–269.8)	228.0 (195.0–280.0)	264.0 (232.0–334.0)	250.0 (205.0–300.0)	227.0 (196.0–275.0)	290.0 (255.0–340.0)	79.2 (58.3–93.8)	72.1 (65.8–79.2)
p-value	0.267	0.015	0.27	0.062	0.037	0.01	0.0007	0.0007	0.112

OR, Operating Room; CABG, coronary artery bypass surgery; AVR, aortic valve replacement; MVR, mitral valve replacement; InOE, Index of Operational Efficiency; sInOE, Surgical Index of Operational Efficiency; NA, Not applicable.

Table 2. Spearman's correlation coefficients for Index of Operational Efficiency (InOE) for various times in the operational pathway.

	Total OR time	Procedure time	Transfer time	Surgeon idling time	Preparation time	Knife-to-skin time
InOE	–1.00 **($p < 0.001$)	–0.940 **($p < 0.001$)	–0.377 **($p < 0.001$)	–0.278 **($p < 0.001$)	–0.378 **($p < 0.001$)	–0.404 **($p < 0.001$)

**$p < 0.05$ is statistically significant.

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Table 3. Total costs for specific times along the operational pathway and analysis of savings and overrun theatre costs.

Total costs for specific times of the operational pathway		Costings for additional Savings (+) and Overruns (-)	
Pathway level	Unadjusted costs (-)/savings (+)	Transfer time	Costing impact
Surgeon idling time	£2,973,360.00	less 10 mins/case	+ £286,920.00
- Transfer time	£2,673,180.00	less 20 mins/case	+ £573,960.00
- Anaesthetic time	£300,180.00		
- Procedure time	£11,508,540.00		
Total operation time	£14,468,100.00	Total theatre overrun cost (4-hr per case = £4800)	- £3,452,790.00 (£2162.05/overrun case)

Note: Based on average Cardiac Operating Room running costs of £1800/hour in a typical tertiary care adult cardiac facility in the National Health Service. All costings are over the 2-year cumulative period of the study. 1GBP = 1.2USD.

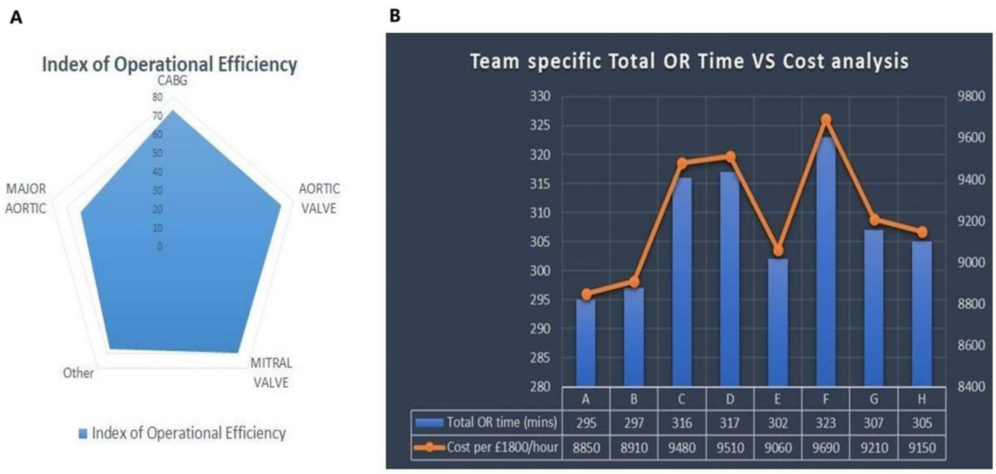

Fig. 3. Specific Indices of Operational Eficiency (InOE) and time vs cost analysis. InOE (numbers represent percentages) comparison between types of procedures (A) and time costing analysis between teams (B).

ther costs were analysed for total OR overruns using 4-hour blocks (£7200 per case) which revealed a total of £3,452,790.00 (average of £2162.05 per case) over the 2-year.

Discussion

OR utilisation has remained the traditional method of assessing operating room performance in the NHS (Faiz et al, 2008). Waiting list pressures following delays from the coronavirus disease-19 (COVID-19) pandemic and junior doctor strikes place significant pressures on the government to create initiatives such as enhanced OR capacity, promotion of day cases operating or satellite OR hubs (Luthra et al, 2023).

Performance metrics used by the NHS to measure efficiency and productivity include start time utilisation, cancellations, number of operations and gap time

Table 4. Improving efficiency in second case delays and case turn over.

Personal	Surgeon and anaesthetist to lead sending for 2nd case
	Nursing to expedite OR cleaning between cases
	ICU matron to make bed available for transfer of 1st case
	Ward staff to make sure 2nd case is ready for transfer
	ODP to ensure timely reception into the anaesthetic room
	NCM to co-ordinate with all for bed availability
	Avoid delays due to surgeon unavailability for WHO checklist
Structural	Easy access to ICU and HDU at the same level
	Proximity of theatre to ICU
	Separate anaesthetic rooms attached to OR
	Reception/holding bays for ward transfers prior to transfer to OR
Organizational	Central case management team for co-ordination
	Send for 2nd case after 1st case is safely off bypass
	Ring fencing of beds on ICU for 1st cases
	Resident transfers and ICU handovers as helping hands
	Reasonable overtime payments for staff for late finish

OR, Operating Room; ICU, Intensive Care Unit; ODP, Operating Department Practitioner; WHO, World Health Organization; HDU, High Dependency Unit.

between operations (Charlesworth and Pandit, 2020). OR time utilization is influenced by many factors including the number of cases scheduled for the day as well as time spent by surgeons not operating (Macario, 2010). OR planning and allocation vis-a-vis cases and resourced manpower (surgeons, anaesthetists, perfusionists, scrub nurses and surgical and anaesthetic practitioners is central to smooth running and efficiency. Invariable factors that affect 'surgeon idling' and 'procedure times' include surgeons arriving late for morning briefings, late starts due to delays in sending, unforeseen problems and difficulties during the procedure prolonging the surgical time, prolonged time spent in haemostasis and training commitments.

'Knife-to-skin' time is a surrogate marker for case start tardiness that adversely affects movement down the operational pathway. Efforts have been directed to avoid delays in the knife-to-skin times at the start of the lists. We have previously shown that knife-to-skin is not an effective marker of utilization or efficiency for the two-case model, although it does reduce first-case delays. It does not predict or influence the middle and latter parts of the pathway, which are more dependent on first-case finish times in a block of 2 cases with a fixed end time for the day. It is a predictor of second-case start times and cancellations but does not predict the overall finish times in the block. The correlation coefficients were strongest for procedure times in our analysis and indicate where additional emphasis can lead to cost savings. Fletcher et al (2017) identified OR turnaround times between cases as one of the biggest contributors to inefficiencies for the day. These inefficiencies build up during the middle part of the pathway and are responsible for late second-case starts and overruns beyond the finish times that are not captured by the knife-to-skin analysis. Table 4 summarizes some of the measures to reduce turnaround times between cases.

Surgeon idling times are constituted by transfer time, anaesthetic line placements, induction, and preparation time (prepping and draping). Girotto et al (2010) suggested methods for improving surgeon idling time and maximising operational efficiency such as increasing proximity to intensive care units, separating anaesthesia bays attached to ORs and maintaining the same structure. Furthermore, eliminating redundant anaesthetic steps, such as Swan-Ganz catheter placements and inappropriate utilisation of trans-oesophageal echocardiograms were also suggested.

Pedagogic activities are a major contributor to delays in the anaesthetic room as well as in the OR. Cardiopulmonary bypass, cross-clamp and total operative times are longer for trainees in both low-risk and high-risk cases (Luthra et al, 2022). Even for Consultant-delivered cases, the preliminary steps and closure are usually performed by trainees. Sternotomy, vein harvest, cannulation, weaning from bypass and hemostasis and closure invariably take longer for trainees although the overall outcomes have been shown to be similar. Most of these steps are completed by trainees even in a consultant-delivered surgery. Cases can be booked for training in protected training time to avoid impacting the overall efficiency of the system. Likewise, certain lists and cases can be run as consultant-delivered ‘skin to skin’ lists for optimization of block finish times.

This is the first study of its kind to use novel efficiency indices to analyse time utilization in the cardiac surgical OR pathway to study cost implications. Our study identified non-surgical factors (e.g., surgeon idling time) leading to impedance of efficient flow through the cardiac surgical pathway. Our key findings were that procedure times constituted the bulk of the OR time. OR efficiencies (InOE and sInOE) correlated best with procedure times. We identified large variations between procedures and teams for total operating times and subsequent costs.

The NHS England Getting It Right First Time (GIRFT) report previously identified that reducing variation could lead to increased efficiency, predictability, better time management, and reduced overall costs for better outcomes. It further recommended an 85% OR touch time utilisation by adopting its recommendations to reduce variation. Adequate prior planning for cases can reduce inefficiencies by preventing overruns. Operational costs can be contained by reducing overruns with protocols and standards specifically targeting efficiencies for optimum allocation and utilization of time and resources (Pandit et al, 2009; Strum et al, 1997; Weinbroum et al, 2003). Time spent during patient transfer and anaesthesia has previously been shown to be a significant factor in operational delays and reduced efficiencies in the OR (Koenig et al, 2011; Sokolovic et al, 2002).

Potential gains in efficiency are mostly achievable in reducing the wasted ‘surgeon idling’. Even small reductions in Transfer time demonstrated significant cost savings of up to £1.7 million over the period of the study. Procedure times are extremely variable and dependent upon surgeon’s practice and idiosyncrasies and most importantly case complexities. Significant adjustments to procedure times for increasing efficiency therefore may not be possible. Surgeon could however take the lead in avoiding late starts and finishes.

Unforeseen factors like pandemics, strikes and staff shortages (ie., Brexit) had devastating impacts on the NHS OR waiting lists, further worsening the bottleneck that already existed. In the context of today's rapid technological advancements, Hassanzadeh et al (2022) have used intuitive machine-learning approaches and suggested artificial intelligence models for predicting OR demands for strategic planning (Luthra et al, 2020).

Live OR performance tracking through the utilisation of electronic dashboards by a dedicated central team may assist in predicting OR time estimations for the block. The framework used for this systematic analysis can help identify correctable inefficiencies in the operational pathways for achieving the GIRFT goal of at least 85% OR touch time utilisation.

This is a single large hospital study; generalisability may, therefore, be limited given the wide variations in health systems, sizes of hospitals, and operational practices. Major variability in the efficiency measures related to dissimilarities in the operational pathways followed within various hospitals or health systems needs to be considered. The sample size is small and the study may be underpowered for the results. The study is based on the 2 cases/8 hr block model with case-based analysis. Cases were not risk-stratified. Times wasted between the first and the second cases were not factored in the model. The complexity of contemporary cardiac cases has increased significantly. Aortic and more complex cases including those needing multiple procedures have a poor model fit. The study was conducted in a large tertiary care teaching hospital. We did not factor in utilization inefficiencies due to the training of anaesthetic and surgical staff. Also, delays in sending due to intensive care beds and nursing staff availability were not appropriately factored in the analysis.

Future studies should be multi-centric within a healthcare system (i.e., NHS) with a larger number of patients for specific generalizability. The novel efficiency indices used in the study will also need further validation in future studies. Although the study pertains to a cardiac operational pathway, its use could be extended to other surgical pathways as well which may not be as complex and resource-intensive. Further, we hope that these novel indices and the methodology developed here can be used for time-costing and resource planning in cardiac surgery centres and aid comparison between individual as well as team practices.

Conclusion

There is a significant variation in utilization and efficiency in cardiac OR. Significant cost savings are possible by reducing variation and increasing efficiency in the operational pathways.

Key Points

- There are significant variations in OR times and efficiencies for different procedures and different teams in the cardiac surgery operational pathway.
- Inefficiencies in the pathway lead to overruns and cost escalation.
- Significant time and cost savings can be made by improvements in the efficiency of the operational pathway in cardiac surgery theatres.

Availability of Data and Materials

All data included in this study are available upon request by contact with the corresponding author.

Author Contributions

SL designed the research study. SL, GH, AE and LV performed the research. SL, SM and TV provided help and advice on content. SL and GH analyzed the data. SL and GH drafted the manuscript. All authors contributed to the important editorial changes in the manuscript. All authors read and approved the final manuscript. All authors have participated sufficiently in the work and agreed to be accountable for all aspects of the work.

Ethics Approval and Consent to Participate

The study was registered as a service improvement project (Safeguard 7872, 29/03/2024) in compliance with the trust data management policies at University Hospital Southampton. Consent was not required due to the nature of the study as a service improvement and a quality initiative. The research was conducted in strict accordance with the ethical principles outlined in the Declaration of Helsinki.

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Conflict of Interest

The authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://www.magonlinelibrary.com/doi/suppl/10.12968/hmed.2024.0836.

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